OKLAHOMA STATE UNIVERSITY

TRACE MINERAL SUPPLEMENTATION OF STEERS: EFFECTS OF ORGANIC AND INORGANIC SOURCES ON PERFORMANCE AND CARCASS CHARACTERISTICS

By

MEHMET BASALAN

Bachelor of Veterinary Medicine

Ankara University

Ankara, Turkey

1992

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1996

TRACE MINERAL SUPPLEMENTATION OF STEERS:

EFFECTS OF ORGANIC AND INORGANIC

SOURCES ON PERFORMANCE AND

CARCASS CHARACTERISTICS

Thesis Approved:

F N Owens

Thesis Adviser

D R Gill

Bob Kropp

Thomas C. Collins

Dean of the Graduate College

This thesis is dedicated in deep love, gratitude and appreciation to people who are significant in my life and who keep me humble.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my major professor, Dr. Fredric N. Owens for his supervision, guidance, encouragement and generosity of time, effort and patience, in the completion of my graduate studies at Oklahoma State University. I also would like to thank my other committee members, Dr. Don R. Gill, and Dr. J. Robert Kropp for their kindness, constructive suggestions and constant encouragement.

My sincere thanks and appreciation are extended to laboratory technician, Joan Summers and secretary, Jamie Sadler for their kindness and generous support.

I also wish to express my sincere gratitude to my fellow graduate students in the Department of Animal Science. Thanks also go to the Turkish people without whom and without whose financial support this achievement would be only a dream.

My family deserves my appreciation for their love, tremendous moral support, valuable prayers and for their belief in me.

Finally, my special thanks to my officemate, and brother in Islam, Mohammed Al-maamari and my friends.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

When essentiality of minerals for livestock first was recognized, mineral supplementation of animals become a major factor that increased productivity of the livestock farming industry (Underwood, 1981). Although plants are considered a major source of minerals for livestock, mineral composition of soils and geochemical processes dictate the composition of plants (Van Soest, 1995). Many minerals constitute the ash of plants and animal tissues. The macro - minerals are needed by living organisms in larger quantities. Trace mineral are required only as part per million and part per billion of the diet. One of the major concerns in animal nutrition is providing an adequate amount of each trace mineral in an absorbable form for a wide variety of feeding situations, production types and rates (Christensen, 1980).

Chemical analysis indicates that plants often do not supply enough minerals to meet an animal requirements (O'Connor, 1992). Although plants in one region may have satisfactory mineral content, animals in this area may exhibit mineral deficiencies because of problems in absorption and (or) utilization. Trace mineral requirements have not been studied in all species and the need for minerals may differ even among breeds within a species. It can be difficult to deplete a mineral from a diet to study deficiency symptoms

and in many field situations, several minerals or nutrients may be deficient simultaneously.

Availability of nutrients depends on both the chemical structure of nutrient or features of an animal's digestive tract. Although concentration of minerals in the diet often limits supply for the animal, bioavailability varies with form of the mineral and presence of interfering compounds; supplementation with nonavailable minerals is wasteful economically and deleterious environmentally (Littell et al., 1995).

Research on bioavailability of minerals first began when mineral requirements first were recognized (Herrick, 1993). For absorption of a mineral from the gastrointestinal system, in most cases, the mineral must be soluble in digestive fluids. However, absorption does not always equal availability for tissue metabolism because some absorbed complexes cannot be metabolized. Retention of minerals is the most widely used measure of utilization although some minerals may accumulate even if they cannot be used in metabolic reactions.

Intestinal conditions can limit mineral utilization (Ammerman, 1995) and interrelationships among minerals may hinder both absorption and utilization (Ashmead, 1993). Such mineral interaction may have either negative or positive impacts on animal performance. However, antagonisms often are responsible for mineral deficiencies.

Minerals are essential normal function of almost every tissues and physiological process. Minerals are needed for maintenance and production

of both hard and soft tissues, providing structure and catalyzing physiological reactions (Ashmead, 1993). Minerals that have roles in enzyme systems, are commonly called metalloenzymes (Underwood, 1977). Today, more than 24 minerals are regarded as essential.

Trace minerals typically are needed as only parts per million of the diet. They function mainly as catalysts for enzyme systems. Nevertheless, growth and health are dependent upon proper balance of all minerals. Most essential minerals play multiple roles. Concentrations in different parts of the living bodies often differ with age and diet. Some minerals serve as buffers in body fluids and in membrane carrier proteins (McDowell, 1992).

Requirements for minerals varies with animal species. The range in the amount of mineral needed or tolerated by various species of animals can be wide or narrow. Low levels may be adequate for maintenance, and higher levels may be needed for growth and reproduction. Upper limits are defined as the maximum tolerable or toxic levels. Factors that may influence dietary requirements and toxicities of minerals include animal species, breed, age, plane of nutrition, mineral form and mineral interactions.

Herbivorous animals obtain their essential minerals primarily from the vegetative parts of plants and grains. Hence, deficiencies vary with plant composition which in turn depends on soil type, climate, and geography. Interactions and antagonisms among minerals and with other nutrients can cause physiological changes and structural abnormalities especially in prenatal or growing animals (Herrick, 1993).

Deficiencies of specific minerals often are difficult to diagnose. Symptoms often are not specific or distinguishable from other nutrient deficiencies. However, with certain minerals, some specific clinical signs are characteristic. Deficiencies can be either acute or chronic, depending upon the soil, plant or feed compositions. The body can warehouse some minerals for use during times of inadequate intake. Hair and skin lesions, reproductive abnormalities and loss of appetite are the generalized symptoms of a mineral deficiency (McDowell, 1992).

Atomic absorption spectrophotometry, neutron activation, induction coupled plasma spectrophotometry, x-ray methods and mass spectrophotometry are the most common techniques used for quantification of minerals. Concentrations of specific minerals in blood, other body fluids and in tissues typically are used to assess the mineral status of animals.

Chelates are metal complexes in which a metal is bound electrostatically to some organic compound. Chelates are formed by coordination of a central element with a peripheral organic compound. By increasing metal solubility, chelating agents often increase mineral absorption (Kratzer and Vohra, 1986). The organic fraction of a chelate that binds an element in more than one place and forms a ring is called a ligand. To form a ring, at least two groups of ligand coordinate with the metal ion. The ligand, being an electron donating agent, attaches to the metal ion.

During the digestion of foods, minerals and natural organic compounds form numerous types of ligands; these facilitate mineral transport throughout the

body (McDowell, 1992). The most important role of chelates in nutrition is increasing mineral bioavailability by enhancing mineral solubility. Low molecular weight complexes bound to minerals can cross the intestine cell wall. Metals are transported through the intestinal membrane by either active transport or passive diffusion. Transport is highly dependent on the electrical charge of complex and equilibrium (Kratzer and Vohra, 1986).

Methionine and lysine are the most common agents for chelating metals. Absorption of amino acid chelates is not inhibited by dietary fats or fiber due to the high formation constant (stability constant) of the chelates (Ashmead, 1993). Because the molecular weight of amino acid chelates generally are less than 800 daltons, they need not be hydrolyzed to cross membrane (Ashmead, 1993).

Despite numerous studies on the performance response to chelates, few studies have compared organic (chelated) with inorganic forms of trace minerals. Manspeaker et al. (1987) concluded that amino acid chelated minerals are absorbed and utilized 3 to 5 times more extensively than inorganic salts. Bull calves had higher rates of gain and superior feed efficiency with amino acid chelate than inorganic mineral salts in the diet. Muscle growth was greaterwhen chelated minerals were fed than when no minerals were provided (Boiling, 1993). However in a study with zinc-methionine (Greene et al., 1987), ADG and feed:gain were not affected by supplementation as compared with zinc oxide supplement. Quality grade and marbling score were higher for the zinc-methionine supplemented cattle than for the cattle supplemented with zinc oxide.

CHAPTER II

GENERAL LITERATURE REVIEW

COPPER

Functions

Essentiality of copper for growth and enzyme systems was demonstrated before 1920 (Baker and Ammerman, 1995). Following this discovery, many naturally occurring nutritional diseases were related to copper deficiency. Copper is found in the nature in rock and supplemented to the diet of the animals as copper metal or chemical compounds containing copper.

Either a low dietary concentration or low absorption can cause a deficiency and deficiencies of copper cause various metabolic disorders (Baker and Ammerman, 1995). Copper performs specific functions in most organs of the body. These include cellular respiration, skeleton formation, cardiovascular function, keratinization, reproductive function and immune system activity (Underwood, 1977).

Both copper and iron are necessary for synthesis of hemoglobin and red blood cells. Copper improves iron absorption and enhances its mobilization (McDowell, 1992). Iron mobilization from the reticulo-endothelial system, hepatic cells, and normoblasts into plasma is controlled by ceruloplasmin. Ceruloplasmin is a protein that contains copper. Ferrous iron is converted to ferritin iron by ceruloplasmin. Most copper in body is bound to ceruloplasmin. This glycoprotein enzyme performs many roles in iron metabolism, oxidation of serum elements and the inflammatory response (Underwood, 1977).

Lysyl oxidase, an enzyme that oxidizes amino acids, contains copper. Lysyl oxidase is necessary for collagen and elastin biosynthesis. Cross-links among collagen fibers are produced when lysine is converted to desmosine. These cross-links dictate the rigidity or elasticity of connective tissues. Of special interest is collagen of the aorta and the heart. Copper also is involved with cellular respiration as a component of cytochrome oxidase. This enzyme is responsible for terminal respiration. As a result of copper deficiency, lambs develop swayback, a disease may be characterized by lack of cytochrome oxidase which decreases ATP synthesis (Owens, unpublished).

One of the major roles of copper in body is in osteoblast activity. Lysyl oxidase is necessary to stabilize bone collagen. Fetal and neonatal lambs are particularly sensitive to copper deficiency. Polyphenyl oxidase (tyrosinase), an enzyme that contains copper, catalyzes the conversion of tyrosine to melanin. With a deficiency of copper, achromotrichia (lack of pigmentation) occurs and black hair becomes gray or reddish.

Disulfide bonds also provide the crosslinks of keratin in wool and hair. Copper is required for the incorporation of these disulfide bonds. Hence, with copper deficiency breaks may occur in the polypeptide keratin chain (Underwood, 1977). A copper-histidine complex is one of the major stimulants for release of GnRH from hypothalamus (Christensen, 1980), so, copper deficiency may stunt growth. Infertility can occur if oxidase activity is reduced, probably due to the interrelationship between copper and sulfur. In research from Oklahoma State University (Kropp, 1993), copper supplementation increased estrus activity and conception rate of beef cows. Copper and Zinc chelates also may increase embryonic viability (Manspeaker and Robl, 1993).

Manganese, zinc and copper are the major minerals that affect immune functions via enzyme systems (Coffey, 1988). Studies with a copper deficient diet for dairy cattle (Ingraham et al., 1987) indicate that copper is involved with synthesis of gammaglobulin and antibody-producing cells. In rats, a copper deficiency increased susceptibility to salmonella infections and reduced proliferation of B lymphocytes (Mayland, 1987).

Requirements and Sources

Copper requirements of livestock are influenced by several dietary factors, especially through its interrelationship with molybdenum and sulfur. Other minerals including Fe, Zn, Pb, and Cd also can affect the dietary requirement for copper (Underwood, 1981). Minimum copper requirements have

been enumerated by the National Research Council publications. Although, providing minerals in fertilizer can change the concentration of many minerals in pasture and forages, copper content of plants is not influenced by copper fertilization (Grace and Clark, 1991). Copper requirements also change with age, sex and level of production (Suttle, 1980).

Copper requirement has been the quantitatively estimated by the factorial method, which basically depends on nutritional balance, slaughter trials, and kinetic tracer studies (Grace and Clark, 1991). Copper requirements also vary with copper bioavailability which varies from 1% to 12% with different sources. Copper concentration in grazed forage may be either toxic or deficient for sheep depending on the concentrations of S and Mo of the grass. Mo and S excesses frequently are responsible for Cu deficiency (Suttle, 1991). Thiomolybdates (TM_1, TM_2, TM_3, TM_4; MoO_3S^{2-}, $MoO_2S_2^{2-}$, $MoOS_3^{2-}$, $MoOS_4^{2-}$) prevent copper from being absorbed by binding copper (Suttle, 1991). Because of this antagonism, the copper requirement varies widely among species (NRC, 1984). For beef cattle, the copper requirement has been estimated to be 8 mg/kg feed DM (NRC, 1984) to 10 mg/kg (NRC, 1996).

The copper concentrations of plants depends on soil structure, climate and stage of maturity (McDowell, 1992). Copper is absorbed very poorly from gastrointestinal tract. Copper in rumen is bound and is not absorbed (Suttle, 1991). Absorption from intestine is regulated by the need of organs. To be absorbed, copper must be of the cupric form. Copper is carried in blood bound to proteins and amino acids. The target storage organ is the liver where copper

is incorporated into enzymes. Copper can be excreted from body both in feces and urine.

Deficiency

Although deficiency symptoms are slightly different among species, lesions typically occur in specific organs. Hypochromic-microcytic and hypochromic-macrocytic anemia are the first symptoms observed with copper deficiency; these are due to altered iron metabolism. Skeletal disorders also occur including bone fractures and deformities which are associated with failure of oxidase activity and reduced osteoblast activity (Underwood, 1977).

Neonatal ataxia is a nervous disorder of newborn lambs and goats. Known as "Swayback", it is characterized by demyelination of spinal cord, encephalopathy, cell necrosis, nerve fiber degeneration and paralysis. These symptoms all are caused by subnormal cytochrome oxidase activity. One of the most characteristic lesions, achromotrichia (loss of pigmentation) appears in hair and wool as the result of depressed tyrosinase activity. Low fertility, delayed estrous, fetal necrosis, hemorrhage and retained placenta are the major reproductive symptoms with a copper deficiency (Underwood, 1977).

Supplementation and Chelation

For poultry and swine, diet supplementation is not necessary under most feeding conditions (McDowell, 1992). In contrast, because of the antagonistic effects of Mo and S, dietary inadequacy of copper is widespread in ruminants. Supplementation to correct the deficiency and maximize productivity can be either oral, ruminal, or parenterally (Wakelin, 1992). Salt licks, feed additives, drinking water solubles and oxidized copper capsules are used for oral supplementation whereas copper metal (needles) is used in ruminal boluses, and copper EDTA and copper glycinate are used for injection.

To overcome low bioavailability, many copper compounds and chelates have been tested (Suttle, 1994). Although inorganic copper compounds are cheaper than organic sources, their availability generally is lower. Cu-EDTA, Cu-DTPA, Cu-TETA and Cu-DOS have been tested as chelates (Suttle, 1994). Amino acid chelates also are readily absorbed. Glycine and histidine are main chelating amino acids. Alanine, phenylalanine and 8-hydroxyquineline also can be used as chelating agents as they increase absorption of copper from intestine of rat (Shah, 1982). Feeding chicks with copper chelates increased availability and, suprisingly, decreased copper toxicity (Kratzer and Vohra, 1986). However for ruminants, this may not be true. In comparison of organic vs inorganic copper sources, copper retention and availability by steers was higher for organic sources (Nockels et al., 1993). However, Pott et al. (1994) concluded that copper bioavailability from organic and inorganic sources was not different

for sheep and Ward and Spears (1991) reported that copper bioavailability from a Cu-lysine complex was equal to that from $CuSO_4$. Feeding ruminants with copper chelates has increased reproductive performance (Kropp, 1993). Brown and Zeringue (1994) concluded that a low pH increased the solubility of copper chelates and with the moderately high pH of the ruminant intestine, the advantage of copper chelates may be reduced.

ZINC

Functions

Zinc is essential for normal growth and health in both plants and animals. Zinc first became of nutritional of interest when it was discovered that a deficiency depressed growth and caused skin lesions (Underwood, 1981).

The metabolic functions of zinc generally are described together with its deficiency symptoms. Zinc is a component of over 200 different enzymes (Greene et al., 1988) including carbonic anhydrase enzymes which catalyzes dehydration of carbonic acid and regulates acid - base balance and regeneration of lactic, malic and alcohol dehydrogenases and nucleotide phosphorylases are other important enzymes that contain zinc (Underwood, 1977). Zinc functions are associated with these enzyme systems.

Zinc is a component of tymidine kinase which catalyzes DNA synthesis. Utilization of amino acids and protein has been increased by zinc supplementation. Zinc also is involved the structure of skin epithelial cells. The major clinical signs of zinc deficiency are parakeratosis and hyperkeratosis. These symptoms are characterized by nuclear degeneration of epithelial cells. When supplied either locally or orally, zinc increases the rate of wound healing. Dermatitis and alopecia are seen during zinc deficiency (Underwood, 1977).

Zinc has effects on spermatogenesis and sexual development (McDowell, 1992) because zinc is associated with gonadal hormones. Inadequate intake or low bioavailability of zinc delays appearance of secondary sex characters and causes hypogonadism (Underwood, 1977), perhaps by its involvement with DNA and cell division (Christensen, 1980). Research from University of Maryland (Manspeaker et al., 1987) has shown that chelated mineral complexes including zinc can increase reproductive performance. Inhibited skeletal development during zinc deficiency may be due to its involvement in collagen synthesis (Underwood, 1977).

Zinc and copper both are necessary for T cell and B cell function of the immune system (Coffey, 1988). Immunoglobulin response after zinc supplementation has been increased (Coffey, 1993). Zinc also is involved in cellular water balance and vitamin A functions in skin (McDowell, 1992). Brain maturation depends on zinc's presence during fetal growth. With zinc deficiency behavior often changes and mental ability is reduced (Underwood, 1977).

Requirements and Sources

The requirement for zinc is affected by many factors. These include age, sex, physiological state of the animals, and form of dietary zinc (Underwood, 1981). Zinc is not stored in body. Hence, it must be supplemented every day (Mayland et al., 1987). Although most forages are quite rich in zinc, its concentration decreases as forage matures. Dietary zinc requirements of sheep and cattle are 25 (Grace and Clark, 1991) to 30 mg/kg diet DM (NRC, 1996). Underwood (1977) suggested that 15 mg zinc is necessary for normal growth and health. However, 15 to 40 mg/kg are needed during pregnancy, lactation and extensive sweating (McDowell, 1992). Zinc absorption may be increased or decreased by chelating materials, and decreased by phytic acid (McDowell, 1992).

Deficiency

Deficiency symptoms vary with species; animals show symptoms in specific organs where enzymes containing zinc are involved in metabolism. The classical lesions visible on skin are parakeratosis and hyperkeratosis, usually around the nostrils, scrotum and face, alopecia, and cracks in the skin. Zinc deficient animals often are weak and sick because of decreased feed intake and retarded growth. Testicular atrophy and depressed emotional behavior are the major symptoms of a mild zinc deficiency. Congenital abnormalities can occur

with severe zinc deficiency in pregnant animals. Besides skin lesions, swollen joints and slow wound healing are characteristic of zinc deficiency in ruminants (Underwood, 1977).

Supplementation and Chelation

Bioavailability of zinc from different sources varies (Ashmead, 1991). Zinc can be added to diets as mineralized salts, salt licks, or in drinking water. Fertilizers containing zinc help grazing animals obtain their dietary needs (McDowell, 1992). Chelation of zinc generally increases availability. Spears and Samsel (1986) compared zinc-oxide and zinc-methionine. Although absorption was similar for these two sources, retention was higher for zinc methionine than zinc oxide. Zinc supplements have improved growth rate and performance in heifers (Spears, 1989). Performance and carcass characteristics have been improved by zinc supplementation of steers (Greene et al., 1988) and chicks and lambs (Smith et al., 1994). Rust (1985) found that steers supplemented with zinc-methionine had superior performance and carcass grade to control groups. Wedekind et al. (1992) compared two inorganic sources with an organic zinc source for chicks. Zinc methionine was more available than inorganic sources for the chicks. Zinc sulfate and zinc methionine were compared for goats by Berrie et al. (1994). Growth rate, feed efficiency, and carcass characteristics were not different between these two zinc sources. In rat study (Fairweather-tait et al., 1992), zinc glycine showed no any

advantage over zinc-carbonate in availability. Organic sources of zinc were more available and accumulated to different concentrations in certain tissues of wether lambs (Rojas et al., 1995). Carcass data tended to be better for cattle fed zinc-methionine than for those fed zinc-oxide (Greene et al., 1988). Zinc-oxide is the most commonly fed source of zinc, but because of its high availability, zinc methionine usage is increasing (Owens, 1986). Zinc-methionine supplementation often has increased performance and decreased morbidity of the newly received cattle (Johnson et al., 1988).

COBALT

Functions

Cobalt is an essential dietary element for nonruminants (as a component of B_{12}) and also needed for microbes in the rumen of ruminants. Cobalt is used for cyanocobalamin (Vitamin B_{12}) synthesis in the rumen. Vitamin B_{12}, in turn, functions in VFA utilization, carbohydrate, nitrogen and nucleic acid metabolism (Corah and Ives, 1992). Other than its role in vitamin B_{12} synthesis, little research has been conducted concerning other biological functions of cobalt (Kennedy et al., 1994).

Ruminal microorganisms use cobalt to produce vitamin B_{12} (Underwood, 1977). In the cecum, vitamin B_{12} can by synthesized by the bacteria, but because B_{12} is absorbed only in the small intestine, B_{12} synthesized in the cecum and large intestine is not be absorbed but is excreted. About 4.5% of vitamin B_{12} is cobalt (McDowell, 1992). Beside vitamin B_{12}, ruminal microorganisms produce many B_{12}-like compounds called pseudo-vitamin B_{12} (Underwood, 1977). Methyl malonyl CoA isomerase (mutase) and methionine synthase are two enzymes that use cobalt or B_{12} as a cofactor (Underwood, 1981). Methyl malonyl CoA mutase catalyses the reaction for the conversion of methyl malonyl CoA to Succinyl CoA, an important step in propionate metabolism. Cobalt also is necessary for methyl group transfer to form methionine from homocysteine by the action of Methyl transferase (McDowell, 1992). The mechanism by which cobalt alters appetite presumably relates to propionate metabolism. Cobalt deficiency depresses propionate clearance from blood so that methyl malonic acid concentration rises in both blood and urine. Higher blood propionate concentrations in turn signal the brain to decrease voluntary feed intake. Methyl transferase also is necessary for nucleic acid synthesis and folacin metabolism. Cobalt compounds can enhance ruminal fiber digestion in vitro experiments (Hussein et al., 1994). A deficiency of cobalt, via reduced activity of methyl malonyl CoA, can result in incorporation of odd numbered-branched chain fatty acids into body fat (Kennedy et al., 1994).

Requirements and Sources

Trace amounts of cobalt are required by both ruminants and nonruminants. Microorganisms in rumen synthesize vitamin B_{12} from cobalt; intestinal microbes in nonruminants also have limited ability to synthesize vitamin B_{12}. Cobalt requirements vary with species; NRC (1984,1985,1989, 1996) has set 0.10 ppm in feed DM as the requirement for most ruminant species. The requirement for cobalt also can be met by supplementing with vitamin B_{12} (McDowell, 1992). The requirement for cobalt depends on both absorption and utilization. Pre-ruminant animals cannot synthesize vitamin B_{12} from cobalt, and ruminants require more cobalt than monogastrics is because ruminants use propionic acid as an energy source and B_{12} is involved in propionate metabolism. Plants do not contain vitamin B_{12}. Therefore, grazing ruminants can become deficient (Underwood, 1977). Hussein et al. (1994) found that feeding the animals cobalt above NRC requirements can increase the extent of cellulose digestion by rumen microbes. Although soil types can affect the cobalt concentration of plants, most forages and green leafy vegetables contain only a small amount of cobalt; most animal products contain adequate amounts except for milk products which are low (McDowell, 1992). Oral cobalt supplementation protects against the rise in plasma aspartate aminotransferase (AST) and glutamate dehydrogenase (GLDH) observed in annual rye-grass toxicity (Davies et al., 1993). Supplemental cobalt also helps prevent parasitic,

bacterial and viral infections, making the animal more resistant to these agents (Suttle and Jones, 1989).

Deficiency

Metabolic deficiency symptoms occur in most organs and tissues. The first characteristic symptom is a loss of appetite that can be reversed by oral administration of cobalt. Cobalt deficiencies often are confused with malnutrition and parasitic infections (McDowell, 1992) because vitamin B_{12} stores in the body are depleted and cobalt concentrations in ruminal fluid are insufficient for ruminal microbes. Such symptoms can be seen even when the liver has a high cobalt content. Poor growth, muscle wasting, normocytic and normochromic anemia, and rough hair coat are other symptoms of a cobalt deficiency (Corah, 1992) as is a reduction in neutrophil function in ruminants (Suttle and Jones, 1989).

Supplementation and Chelation

Adequate dietary cobalt is needed for vitamin B_{12} synthesis by the microflora in rumen. The dietary cobalt requirement varies with animal species, age, and nutritional status as well as the chemical form of cobalt in the diet. Although cobalt is highly absorbed by nonruminants, microorganisms in

ruminants incorporate only about 3% of dietary cobalt into vitamin B_{12} (McDowell, 1992). Although research on cobalt-proteinate is limited, availability of cobalt from most sources for ruminants appears quite similar (Owens, 1986). Lopes-Guisa and Satter (1991) indicated that supplementation with cobalt above NRC requirements can increase digestibility of low quality forages. Including cobalt in fertilizer can increase the cobalt content of soil and grass to help met the cobalt requirement of grazing ruminants (O'Connor, 1992). Cobalt should be supplemented orally, not injected, to achieve adequate vitamin B_{12} synthesis. Cobalt oxide is the most common compound supplemented to diets. Dietary EDTA and nicotine-hydroxamic acid can decrease cobalt absorption; alanine, phenylalanine, histidine, and 8-hyroxyquinoline can increase intestinal bioavailability of cobalt in rat (Shah, 1982).

MANGANESE

Functions

The nutritional importance of manganese has been studied for many years (Underwood, 1981). An essential trace mineral for both plants and animals, manganese appears more important for commercial poultry than for other domestic animals.

Manganese functions are mainly of two types: a) many enzymes are activated by manganese and b) several enzymes contain manganese. Hydrolases, kinases, decarboxylases and transferases can be activated by either manganese or magnesium. Metalloenzymes that contain manganese include pyruvate carboxylase, superoxide dismutase and avimanganin (Underwood, 1977). With a manganese deficiency, specific organs in which these enzymes catalyze specific reactions are the first to show deficiency symptoms.

Manganese is associated with mucopolysaccaride synthesis through activation of glycosyltransferase. Mucopolysaccarides of cartilage and bone are necessary for bone growth and health. Manganese activates polymerase and galactotransferase, two enzymes vital for chondroitin sulfate synthesis.

Manganese also is involved with the reproductive systems of both males and females. Manganese is involved with metabolic reactions of the fetus that include bone growth, nervous system development, and pigmentation of skin (Underwood, 1977). Manganese affects libido, estrous, fertility and gonadal hormone synthesis (McDowell, 1992).

Through its relationship with choline, manganese affects lipid metabolism in body. Manganese is an activator of enzymes essential for choline and cholesterol synthesis (Jenkins and Kramer, 1991). Manganese also is involved with protrombin formation, activating one of the transferases. The enhancing effect of vitamin K on blood clotting is depressed during a deficiency of manganese (Underwood, 1977). Glucose utilization also is under the control of

manganese, because manganese is associated with insulin synthesis by some unknown mechanism (McDowell, 1992). Being involved in oxidative phosphoylation, Manganese is involved in ATP production. Finally, manganese plays a role in the immune response; dietary manganese and zinc supplements speed recovery from IBRV infections in steers (Chirase et al., 1994).

Requirements and Sources

Manganese requirements for optimum growth and health have been proposed by the NRC (1984, 1985, 1989). Manganese requirements of livestock vary with species, physiological status of animal, and the chemical form of dietary manganese. About 20 ppm in feed DM is required for growth of beef cattle (NRC, 1984) but 40 ppm may be needed for reproduction (NRC, 1996). The manganese requirement is influenced by Ca and P intake (McDowell, 1992). The manganese requirement of chickens, at 30 to 60 mg/kg feed DM, is higher than for other domestic animals (Smith et al., 1995). The outer layers of grain contain more manganese than inner layers and the manganese concentration of plants is highly dependent on soil factors. Animal products are considered to be poor sources of manganese (Underwood, 1977).

Deficiency

Deficiency symptoms include skeletal abnormalities, reproductive disorders, and defects in lipid and carbohydrate metabolism (Underwood, 1981). Perosis in chicks is the most common sign of a manganese deficiency. Lesions of skeletal systems cause weakness and abnormal shape. Infertility and fetal deformities are seen commonly and survival of fetus often is threatened with an endemic deficiency (Abdelrahman and Kincaid, 1992). Reduced libido, failure of spermatogenesis, abortion and small ovaries are characteristic reproductive disorders. Fat deposition is reduced and carbohydrate metabolism disorders occur during a manganese deficiency.

Supplementation and Chelation

Although most plant foodstuffs contain an adequate level of manganese, supplementation is economical insurance. Manganese sulfate and manganese oxide are the most commonly supplemented forms of manganese. However, bioavailabilities of these inorganic forms availabilities are very low compared with organic manganese sources (McDowell, 1992). Jenkins and Kramer (1991) found that providing manganese at ten times to fifty times the NRC requirements altered lipid distribution. Inorganic vs organic manganese have been compared with chicks (Smith et al., 1995); biological availability of organic manganese sources was higher than for inorganic sources. For rats, an manganese amino

acid chelate was compared with manganese chloride. The manganese content of tissues was higher for rats receiving the chelated manganese than those fed the chloride (Ashmead, 1991). Alanine, phenylalanine, histidine are the major natural chelating agents (Shah, 1981). Supplementation with organic manganese together with zinc has helped sustain body weight of IBRV-stressed steers (Chirase et al., 1994). Supplemental trace minerals including Cu, Zn, Mn and Se have increased average daily gain of feedlot steers (Boila, 1987).

CHAPTER III

EFFECTS OF TRACE MINERAL SUPPLEMENTS ON PERFORMANCE OF FEEDLOT STEERS

M. Basalan, W. J. Hill, D. S. Secrist, F. N. Owens, C. A. Strasia, D. R. Gill, and A. B. Johnson

Story in Brief

Response of steers to trace minerals was examined in a 218 d feedlot trial using 72 crossbred steer calves (227 kg. initially) in 12 pens. The "Control" steers received no supplemental Co, Cu, Mn or Zn; "4-Plex®" steers received organic forms of these four minerals; "inorganic" steers received only inorganic forms of these four minerals. The 95% concentrate diet consisted of whole corn, cottonseed meal, urea, and 5% cottonseed hulls. Co, Cu, Mn and Zn concentrations of the control diet were .08, 4.3, 20, and 26 ppm; supplemented diets contained 2.8, 13.9, 22, and 40 ppm; NRC (1984) minimals are .10, 8, 40, and 30 ppm. During the first 104 d and averaged over the total trial, mineral supplements or sources did not alter performance. But during the last 114 d, ADG was greater for steers receiving trace minerals. Feed intake tended to be lower for 4-Plex® than inorganic steers, and feed:gain ratio was slightly better for

4-Plex® than inorganic or control steers. Carcass characteristics did not differ. Added trace mineral tended to increase Cu concentration in blood and liver and Zn concentration in blood. Compared to steers fed inorganic forms, 4-Plex® steers had higher liver Co. Liver Mn was notably low. Apparently, these newly weaned calves had adequate stores of these trace minerals for normal feedlot performance for several months but rate of gain stalled later when minerals were not added. The 7% efficiency advantage for steers fed 4-Plex® over steers fed inorganic minerals late in the study may reflect either a metabolic advantage of chelated minerals or simply a dietary inadequacy of inorganic minerals.

(Key Words: Steers, Performance, Trace Minerals)

Introduction

Essential trace minerals include Co, Cu, Fe, I, Mn, Se, and Zn (Owens et al., 1994). Although trace mineral deficiencies can reduce feed intake and depress efficiency, addition of trace minerals above some upper limit also can prove harmful (Owens, 1988). Several studies on the bioavailability of complexed minerals suggest that organic compounds have a superiority over inorganic forms (Ashmead, 1991; Manspeaker et al., 1987; Spears, 1989; Wedekind et al., 1992); others studies suggest that there is no advantage of organic metal complexes over inorganic forms (Greene et al., 1988; Rojas et al., 1995). Although average daily gain and feed efficiency have been measured in

these latter studies, metabolic effects and specific responses were not investigated.

Trace mineralized salt and commercial trace mineral supplements often do not supply as much copper, cobalt, manganese, and zinc as recommended by the NRC (1984, 1996). Additionally, certain consultants have questioned whether trace minerals even need to be supplemented to diets for finishing cattle. Proof that growing and finishing cattle can benefit from supplementation with these trace minerals is based largely on measurements other than performance. In addition, sources of these trace minerals range from the oxides and sulfates, some of which have limited availability, to organic forms chelated with amino acids or protein which usually are more useful to animals.

Many chelated mineral research studies are difficult to interpret due to lack of negative or positive inorganic control treatments to compare with the organic form of the mineral. In studies that have compared inorganic with organic forms of minerals, most have used a specific level of supplementation of both forms and have not used a negative control to determine whether the supplemental mineral is needed or beneficial. In other studies, inorganic minerals have not been provided to compare with the chelated mineral.

The purpose of this experiment was to evaluate the need for supplementing diets for rapidly growing feedlot steers with four trace minerals (cobalt, copper, manganese and zinc) and to compare the performance responses from supplementing near levels recommended by the NRC (1984) with either an organic or inorganic form of these four minerals.

Materials and Methods

Animals. English X Exotic, crossbred, spring-born calves (n=72) were weaned from two commercial cow herds at Oklahoma State University in October 1994. The cattle were vaccinated with modified live virus 4-way respiratory and 7-way clostridial vaccines at weaning. On November 21, 1994 these cattle were transported 450 kms. (5 hours) to the Panhandle State University research facility at Goodwell, OK. Upon arrival, the cattle were weighed, revaccinated and treated with Ivomec® pour-on for parasite control. On November 22, 1994 (d 0) the cattle were stratified into four weight blocks and assigned randomly to one of three treatments.

Pelleted protein supplements were formulated based on urea and cottonseed meal utilizing either 1) no supplemental copper, cobalt, manganese or zinc, 2) organic (Zinpro 4-plex®) forms of these minerals or 3) inorganic forms (sulfate form) of these four minerals at nearly the same concentration as provided by the organic form. Cobalt, Cu, Mn and Zn concentrations of the control diet were .08, 4.3, 20, and 26 ppm; supplemented diets had 2.8, 13.9, 22, and 40 ppm; NRC (1984) minimals are .10, 8, 40, and 30 ppm. All other minerals were supplemented to meet or exceed requirements estimated by the NRC (1984). The steers were housed in twelve partially covered pens with covered feed bunks. Each treatment had four pens and 24 calves (6 calves per

pen). The cattle were implanted with Synovex-S® on d 30 and reimplanted with Revalor-S® on d 99.

Diets. Isonitrogenous and isocaloric diets were available free choice. The basal ingredients included whole shelled corn (84.4%), cottonseed hulls (5.0%), and a supplement pellet (10.6%). All ingredients were analyzed at a commercial laboratory for dry matter, crude protein, calcium, phosphorus, potassium and trace minerals. These diets (table 1) differed only in the form or presence of these four trace minerals.

Data Collection and Analysis: Prior to starting the trial, liver biopsy and blood samples were obtained from 24 of the calves to assess trace mineral status. The procedure explained by Anderson (1992) was used for taking liver samples. Skin over the biopsy site was clipped and prepared for aseptic insertion of the biopsy instrument. Lidocaine (2%) was infiltrated locally for reducing animal reaction, but cattle still respond while peritoneum was penetrated. A small stab wound was made in the skin with a No. 15 scalpel blade at the site of insertion of the biopsy tool. The place where the site of insertion is a line drawn from the point of the tuber coxae to the point of the shoulder. The biopsy instrument was inserted where this line crosses the 11th intercostal space. The location of puncture site can be determined by drawing a horizontal line cranial from the middle of the right paralumbar fossa. A tru-cut biopsy instrument was used for taking liver biopsy samples. The biopsy needle was directed slightly craniad and ventrad to keep the tip of biopsy instrument in the liver parenchyma. Buffered formalin (2.5%) was used to fix small needle biopsy specimens of liver

to prevent dehydration and distortion of tissue. All calves were weighed and feed samples were taken at 28 d intervals. All steers were slaughtered at Excel Corporation, Dodge City, KS after being fed for 218 days. Carcass data were collected after a 48 hr chill. Immediately prior to slaughter, blood and hair samples were obtained from each calf. Samples of blood and liver tissue were obtained from each steer during processing at the packing plant. All blood and tissue samples were analyzed at the Michigan State Diagnostic Laboratory. For statistical analysis, comparisons of interest were 1) whether supplementing with these four supplemental minerals averaged across the two forms produced any response compared with the unsupplemented steers, and 2) whether responses differed due to the form of supplemental trace minerals.

Results and Discussion

Cattle Performance: Performance data are summarized in Table 2. Average daily gain was calculated for the entire period on a carcass adjusted (dressing percentage 62%) basis. Period gains (d 0 to 104 and d 104 to 218) were calculated by regressing individual shrunk weights collected monthly against time on feed. Rate of gain, feed intake, and feed efficiency were not affected by the presence or form of TM supplementation during the first 104 days on feed. Failure of supplemental trace minerals to influence performance during this period may reflect adequate stores of these minerals at the start of the feeding period or overestimation of requirements for these trace minerals.

During the second half of the trial, however, steers receiving supplemental trace minerals had greater (P=.03) daily gains than did unsupplemented steers. Feed intake tended to be greater during the second period (P=.09) and over the total trial (P=.08) for steers supplemented with inorganic than with the organic form of these minerals, but ADG was not different between the two forms of TM supplementation. Equal rate of gain with slightly lower feed intake means that steers supplemented with 4-plex tended to have slightly improved feed efficiencies when compared with steers receiving no supplemental trace minerals or inorganic trace minerals. Averaged over the total trial, feed efficiency did not differ statistically due to TM supplementation although a numeric and economic advantage from supplementation trace minerals of either form was evident. Relatively poor performance by all cattle in the first period tended to mask effects on feed efficiency. The more rapid gain of supplemented steers during the second period probably reflects a deficiency of one or more of these trace minerals among the unsupplemented steers.

The lack of performance response to trace mineral supplementation during the first half of the trial probably reflects initial status of these cattle. Mineral status of cattle may be inadequate from certain regions of the country, especially if supplemental minerals are not provided prior to weaning. Mineral status at the start of feeding period probably is the key factor determining when performance will be depressed due to a trace mineral deficiency.

Spears (1988) reported that zinc supplementation increased average daily gain and feed:gain during the first 56 days but not during a full 126 day

study. This might be due to low zinc status of the cattle initially. Boila (1987) supplemented a feedlot diet with Cu, Zn, Mn and Se increased growth rate and feed efficiency. Boling (1993) concluded that rate of gain and feed efficiency of eleven to twelve month-old bull chianina beef calves was higher during the last month of their 10-months when they were supplemented with chelated trace minerals. Spears and Samsell (1986) in a 126 day feeding trial found that zinc methionine supplemented heifers gained faster and more efficiently than control heifers or heifers supplemented with zinc oxide. However, several studies (Greene et al., 1988.; Breathour, 1988) have found no significant difference in performance between organic and inorganic zinc sources which matches our results.

Carcass characteristics. Carcass data are summarized in Table 3. Carcass characteristics did not differ due to TM supplementation. The cattle had a mean 746 lb. carcass, a dressing percentage of 62.7% and 34.3% graded choice. The liver condemnation rate averaged 18.9%. Considering the small number of steers in this study, one might not expect to detect differences in carcass measurements. Only by combining data from numerous studies can carcass effects be assessed accurately.

In a study with 196 steers in Montana, Rust (1985) indicated that cattle supplemented with zinc methionine had similar average daily gain and feed to gain ratio as control animals, but they had a higher quality grade and greater KPH. Greene et al. (1988) also reported that quality grade and marbling score were higher in steers supplemented with zinc-methionine than those

supplemented with zinc oxide. External fat thickness and KPH also were higher in zinc-methionine supplemented than in control steers. Martin et al. (1987) found that zinc-methionine did not significantly alter carcass characteristics of finishing cattle. In another study from Oklahoma State University, it was indicated that trace mineral supplementation to NRC requirements may improve marbling score and external fat thickness (Dubeski et al., 1990).

Blood and liver mineral concentrations. At the start of the trial, blood concentrations of calcium (Ca), copper (Cu), magnesium (Mg), phosphorus (P), zinc (Zn), sodium (Na) and potassium (K) all were above the minimum concentrations suggested by both Puls (1988) and Michigan State Diagnostic Laboratory (Table 4) to be adequate. This indicates that our steers probably had adequate status for these minerals. Additionally, liver concentrations of Ca, Cu, iron(Fe), Mg, P, Zn, cobalt (Co), Na, sulfur (S) and K all were above the suggested minimum values (Table 5). The only minerals that fell below the suggested minimums were for Fe in blood and Mn in liver. Hence, at the start of the feeding trial, our steers probably had adequate mineral status except perhaps for Mn. Certainly, cattle from various regions of the country where forages are deficient in minerals and from ranches where growing calves and their dams do not receive supplemental mineral may enter the feedlot deficient in one or more trace minerals.

At the end of the feeding period, blood and liver data indicated that most measured minerals for both supplemented and unsupplemented cattle were adequate. Lower than recommended concentrations were noted for Cu in blood

and Fe, Mn, and Na in liver tissue. Blood Cu concentration, classified as deficient for every animal, was lower at the end than at the start of the trial; it decreased less ($P<.04$) for steers that received supplemental trace minerals. Final liver Cu also was lower ($P<.05$) for unsupplemented cattle but remained numerically above the initial concentration for these steers. Although blood Fe suggested a deficiency at start of the trial, blood concentrations were higher at the end and had increased to a greater degree when trace minerals were supplemented even though none of our supplements provided iron. In contrast, liver concentrations of iron dropped ($P<.05$) below initial levels to levels considered deficient for by the end of the study for every steer in the trial.

Although neither blood nor liver concentrations of magnesium changed significantly during the trial, blood Mg tended to increase while liver Mg decreased. Liver Mg decreased to a lesser ($P<.01$) extent with inorganic than organic mineral supplementation even though Mg was not provided in either supplement. Liver and blood concentrations of P were not significantly affected over the duration of the trial, but final blood P levels were greater ($P<.05$) for organic than inorganic supplemented cattle even though neither was different from control steers. Final liver Mn concentrations were numerically greater than initial levels for all cattle but remained consistently below the concentrations recommended.

Blood Zn concentrations increased from the start to the end of the trial, increasing to a greater ($P=.08$) degree for supplemented than for unsupplemented cattle with no difference due to trace mineral source. Liver Zn

concentrations decreased for all groups from start to finish. Liver Co concentrations decreased during the trial with organic mineral supplemented cattle decreasing (P<.01) to a lesser degree than cattle supplemented with inorganic cobalt. Blood Na concentrations changed very little during the trial whereas liver Na decreased to a level considered deficient for all cattle; levels and changes were not influenced by trace mineral supplementation or source. Liver S levels tended to increase during the trial with no difference due to treatment. Blood K levels increased for all cattle by the end of the trial, with concentrations increasing to a greater (P<.05) extent for supplemented than for unsupplemented cattle. Liver K decreased slightly with the concentrations remaining higher (P<.03) for steers receiving inorganic minerals than those receiving 4-plex.

Blood concentrations of minerals classified by cattle breed are reported in table 6. Breeds differed (P<.05) in blood Cu, Ca, Fe, P, Zn, and Na concentrations. Blood Ca was higher (P<.05) for Angus than others breeds except Hereford. Although blood Cu concentration was higher for Gelbvieh than others breeds, the only significant difference was between Gelbvieh and Crossbred cattle (P<.05). Blood Fe concentration was higher (P<.05) for Limousin than Hereford and crossbred cattle (P<.05). Blood P, Zn and Na concentrations for Limousin also tended to be higher than for other breeds.

Liver concentrations of minerals are presented in table 7. Liver Ca concentration was higher (P<.05) for limousin than for crossbred cattle. Liver Cu concentration was higher (P<.05) for Hereford than crossbred cattle (P<.05).

Although the liver Cu concentration of Gelbvieh was quite high, concentrations were similar in Angus, Gelbvieh and Limousin. The liver Mn concentration of Gelbvieh was higher ($P<.05$) than of Angus, Crossbred and Limousin steers. The liver Na concentration was higher ($P<.05$) for Angus than Limousin ($P<.05$) steers.

These results suggest that Gelbvieh and Hereford may make more efficient use of Cu and Mn. This is opposite the conclusion of Littledike et al. (1995). They found that Limousin cattle were more efficient than other breeds in Cu, Zn and Fe use. Limousin may have superior absorption, transport and storage of Zn, Fe, P and Na but not of Cu and Mn.

Ward et al. (1995) compared with Angus, Simmental and Charolais cattle; they were found that Simmental and Charolais cattle did not maintain as high plasma Cu concentration as Angus when fed an identical diet which includes 10 mg/kg Cu. Trends in blood and liver Cu in our study support this finding although Angus had only an average Cu concentration in liver.

In summary, except for Cu, blood minerals increased or did not change from initiation to termination of the 218d feeding trial. Liver mineral concentrations were more erratic; P, Mn and S increased while other minerals decreased. The major impacts of mineral supplementation on final mineral concentrations were for Cu, which increased in mineral supplemented cattle but decreased in unsupplemented cattle. The only impacts of mineral source were for liver Co, which was much greater with supplementation with 4-plex, and a trend for higher Mn with 4-plex. Although Co status appeared adequate, liver

concentrations of Mn suggest that it may have been marginal deficient. Whether the slight improvement in Mn status with 4-plex is responsible for the trend for improved feed efficiency in the last half of the feeding period for cattle receiving 4-plex is unclear. Note, however, that even with supplementation, the dietary concentration of Mn with both 4-plex and inorganic minerals at 22 ppm remained below the concentration suggested as required by NRC (1984) for growing cattle (30 ppm) but above that recommended by NRC (1996) of 20 ppm.

Conclusions

The decision to use an organic or inorganic source of trace minerals should be based on cattle performance and economics. Extensive data with nonruminants and some data with ruminants indicate that organic forms usually are absorbed more completely; thereby, less mineral needs to be fed when the mineral is in organic form than when it is in the inorganic form. This difference might be important for avoiding adverse effects of excess Cu and Zn on ruminal fermentation and when one considers the environmental impact of animal waste. With current prices and regulatory practices, for a given cost, more mineral can be supplied from an inorganic than an organic form. Nevertheless, total cost even for organic forms of minerals should be less than $1 per ton of feed, a minor cost relative to the sacrifice in animal efficiency observed with mineral deficiencies. Even among inorganic minerals forms, usefulness differs. Availability generally is greater from sulfate than oxide forms.

Although weaned calves may not require trace mineral supplements for adequate performance for the first 100 days in the feedlot, other cattle deficient at the start may respond immediately to supplementation. Until some less costly methods are developed for determining mineral status at the start of a feeding period, supplementation is more economical than assessment of status. For large feedlots, analysis of liver samples gathered at necropsy of cattle that have been fed for several months should prove useful to assess trace mineral status of cattle and thereby of the finishing diet. Considering that feedlot diets can be supplemented to recommended levels with inorganic trace minerals for less than 20 cents per ton of feed, trace minerals are economical insurance. Until more definitive requirements are established, NRC (1984) recommendations should be used as minimum concentrations.

Literature Cited

Abdelrahman, M. M., and Kincaid, R. L. 1993. Deposition of copper, manganese, zinc, and selenium in bovine fetal tissue at different stages of gestation. J. Dairy Sci. 76:3588-3593.

Ammerman, C. B. 1995. Methods for estimation of mineral bioavailability. In: Ammerman, C. B., Baker, D. H., and Lewis, A. J. (Ed.). Bioavailability of Nutrients for Animals. pp. 5-32. Academic Press, Inc. San Diego, California.

Anderson, N. V. 1992. Veterinary Gastroenterology. (Sec. Ed.) Phiger, Philedelphia. pp. 69.

Ashmead, D. H. 1991. Comparative intestinal absorption and subsequent metabolism of metal amino acid chelates and inorganic metal salts. Biological Trace Element Research. pp. 307-319. American Chemical Society, Washington, DC.

Ashmead, D. H. and Zunino, H. 1993. Factors which affect the intestinal absorption of minerals. In: D. H. Ashmead (Ed.) The Roles of Amino Acid Chelates in Animal Nutrition. pp. 21-45. Noyes Publications. Park Ridge, New Jersey, U. S. A.

Baker, D. H., and Ammerman, C. B. 1995. Copper bioavailability. In: Ammerman, C. B., Baker, D. H., and Lewis, A. J. (Ed.). Bioavailability of Nutrients for Animals. pp. 5-32. Academic Press, Inc. San Diego, California.

Berrie, R. A., Hallford, D. M., Galyean, M. L.,Birch, M. W., Christensen, B. L., Schneider, F. A., and Ortiz, A. 1994. Growth and carcass characteristics of lambs fed supplemental zinc sulfate or zinc methionine. ASAS Western Section. 45:137-139

Boila, R. J. 1987. Supplementary trace minerals for the feedlot finishing of beef steers. Can. J. Anim. Sci. 67:765-774.

Boling, J. A. 1993. The feeding of amino acid chelate supplements to beef calves. In: D. H. Ashmead (Ed.) The Roles of Amino Acid chelates in Animal Nutrition. pp. 187-203. Noyes Publications, Park Ridge, New Jersey, U. S. A.

Brethour, J. R. 1988. Trials with zinc methionine at the forth hays branch experiment station. Zinpro Seminar on Zinc methionine in ruminants. Zinpro Corporation, Bloomington, MN.

Brown, T. F., and Zeringue, L. K. 1994. Laboratory evaluations of solubility and structural integrity of complexed and chelated trace mineral supplements. J. Dairy Sci. 77:181-189.

Chirase, N. K., Hutcheson, D. P., Thompson, G. B. and Spears, J. W. 1994. Recovery rate and plasma zinc and copper concentrations of steer calves fed organic and inorganic zinc and manganese sources with or without injectable copper and challenged with infectious bovine rhinotracheitis virus. J. Anim. Sci. 72:212-219.

Christensen, D. A. 1980. Trace minerals for reproduction in beef cows (Copper, zinc and manganese). Alberta Cattle Commission Research Symposium, Red Deer, Alberta. pp. 32-51.

Coffey, R. T. 1988. Predisposition to disease: the inter-relationship of the bovine immune response and trace element physiology. Bovine Practitioners. 23:138-143.

Coffey, R. T. 1993. The use of amino acid chelates to enhance the immune system. In: D. H. Ashmead (Ed.) The Roles of Amino Acid Chelates in Animal Nutrition. pp. 117-139. Noyes Publications. Park Ridge, New Jersey, U. S. A.

Corah, L. R., and Ives, S. 1992. Trace minerals in cow herd nutrition programs. Agri-Practice. 13(4):5-7.

Davies, S. C., Williams, I. H., White, C. L., Allen, J. G., Edgar, J. A., Cockrum, P. A., and Stewart, P. 1993. Protective effect of cobalt against apparent liver damage in sheep exposed to toxic annual ryegrass. Australian Veterinary J. 70(5):186-187.

Dubeski, P. L., Owens, F. N., and Gill, D. R. 1990. Trace mineral supplementation of cattle fed finishing rations. Oklahoma Agr. Exp. Sta. Res. Rep. MP-129:93-99.

Fairweather-Tait, S. J., Fox, T. E., Wharf, S. G., and Ghani, N. A. 1992. A preliminary study of the bioavailability of iron and zinc-glycine chelates. Food Additives and Contaminants. 9(1):97-101.

Galyean, M. L. 1996. Disparity between requirements for zinc and current fortification levels in beef cattle finishing diets. Proc. of the Southwest Nutr. Conf. pp. 27-31. University of Arizona, Tucson, Arizona.

Grace, N. D. and Clark, R. G. 1991. Trace element requirements, diagnosis and prevention of deficiencies in sheep and cattle. In: Tsuda, T., Sasaki, Y., and Kawashima, R. (Ed.) Physiological Aspects of Digestion and Metabolism in Ruminants. Proc. of the Seventh International Symposium

on Ruminant Physiology. pp. 321-346. Academic Press, Inc., San Diego, California.

Greene, L. W., Lunt, D. K., Byers, F. M., Chirase, N. K., Richmond, C. E., Knutson, R. E. and Schelling, G. T. 1988. Performance and carcass quality of steers supplemented with zinc oxide or zinc methionine. J. Anim. Sci. 66:1818-1823.

Herrick, J. B. 1993. Minerals in animal health. In: Ashmead, D. H. (Ed.) The Roles of Amino Acid Chelates in Animal Nutrition. pp. 154-167. Noyes Publications, Park Ridge, New Jersey.

Hussein, H. S., Fahey, G. C., JR., Wolf, B. W. and Berger, L. L. 1994. Effects of cobalt on in vitro fiber digestion of forages and by-products containing fiber. J. Dairy Sci. 77:3432-3440.

Ingraham, R. H., Kappel, L. C., Morgan, E. B. and Srikandakumar, A. 1987. Correction of subnormal fertility with copper and magnesium supplementation. J. Dairy Sci. 70:167-180.

Jenkins, K. J., and Kramer, J. K. G. 1991. Effect of excess dietary manganese on lipid composition of calf blood plasma, heart, and liver. J. Dairy Sci. 74:3944-3948.

Johnson, B. D., Hays, V. S., Gill, D. R., Smith, R. A., Owens, F. N., and Ball, R. L. 1988. Zinc methionine for newly received Stocker cattle. Oklahoma Agr. Exp. Sta. Res. Rep. MP-125:111-116.

Kennedy, D. G., Kennedy, S., Blanchflower, W. J., Scott, J. M., Weir, D. G., Molloy, A. M., and Young, P. B. 1994. Cobalt-vitamin B_{12} deficiency causes accumulation of odd-numbered, branched-chain fatty acids in tissues of sheep. British J. Nutr. 71:67-76.

Kratzer, H. F. and Vohra, P. 1986. (Ed.) Chelates in Nutrition. CRC Press, Inc. Boca Raton, Florida, U. S. A.

Kropp, J. R. 1993. The role of copper in beef cattle fertility. In: Ashmead, D. H. (Ed.) The Roles of Amino Acid Chelates in Animal Nutrition. pp. 154-167. Noyes Publications, Park Ridge, New Jersey.

Littell, R. C., Lewis, A. J., and Henry, P. L. 1995. Statistical evaluation of bioavailability assays. In: Ammerman, C. B., Baker, D. H., and Lewis, A. J. (Ed.). Bioavailability of Nutrients for Animals. pp. 5-32. Academic Press, Inc. San Diego, California.

Littledike, E. T., Wittum, T. E. and Jenkins T. G. 1995. Effect of breed, Intake, and carcass composition on the status of several macro and trace minerals of adult beef cattle. J. Anim. Sci. 73:2113-2119.

Lopez-Guisa, J. M., and Satter, L. D. 1992. Effect of copper and cobalt addition on digestion and growth in heifers fed diets containing alfalfa silage or corn crop residues. J. Dairy Sci. 75:247-256.

Manspeaker, J. E., and Robl, M. G. 1993. The use of amino acid chelates in bovine fertility and embryonic viability. In: Ashmead, D. H. (Ed.) The Roles of Amino Acid Chelates in Animal Nutrition. pp. 140-153. Noyes Publications, Park Ridge, New Jersey.

Manspeaker, J. E., Robl, M. G., Edwards, G. H., and Douglass, L. W. 1987. Chelated minerals: their role in bovine fertility. Veterinary Medicine. pp. 951-956.

Martin, J. J., Strasia, C. A., Gill, D. R., Hicks, R. B., Ridenour, K., Dolezal, G., and Owens, F. N. 1987. Effect of zinc methionine on live performance and carcass merit of feedlot steers. Oklahoma Agr. Exp. Sta. Res. Rep. MP-119:344-350.

Mayland, H. F., Kramer, T. R., and Johnson, W. T. 1987. Trace elements in the nutrition and immunological response of grazing livestock. Proc. Grazing Livestock Nutr. Conf. pp. 101-113.

McDowell, L. R. 1992. Minerals in Animal and Human Nutrition. Academic Press, Inc. San Diego, California.

Nockels, C. F., DeBonis, J. and Torrent, J. 1993. Stress induction affects copper and zinc balance in calves fed organic and inorganic copper and zinc sources. J. Anim. Sci. 71:2539-2545.

NRC. 1984. Nutrient Requirements of Beef Cattle (6th ED.). National Academy Press, Washington, DC.

NRC. 1985 Nutrient Requirements of Sheep (5th ED.). National Academy Press, Washington, DC.

NRC. 1989. Nutrient Requirements of Dairy Cattle (6th ED.). National Academy Press, Washington, DC.

NRC. 1996. Nutrient Requirements of Beef Cattle (7th ED.). National Academy Press, Washington, DC.

O'Connor, M. B. 1992. Copper and cobalt topdressing. In Trace Elements in Ruminants. Proc. 22nd Seminar. pp. 121-124. Massey University, New Zealand.

Owens, F. N. 1986. Trace mineral supplements for feedlot cattle. . Proc. of the Southwest Nutr. and Mgmt. conf. pp. . University of Arizona, Tucson, Arizona.

Owens, F. N. 1988. Labeling trace mineral deficit areas and how to deal with them. Beef Magazine. pp. 29-36 and 98.

Owens, F. N. 1994. Trace minerals for feedlot cattle - an update. Proc. of the Southwest Nutr. and Mgmt. conf. pp. 29-44. University of Arizona, Tucson, Arizona.

Pott, E. B., Henry, P. R., Ammerman C. B., Merritt, A. M., Madison, J. B. and Miles, R. D. 1994. Relative bioavailability of copper in a copper-lysine complex for chicks and lambs. Anim. Feed Sci. Tech. 45:193-203.

Puls, R. 1988. Mineral levels in animal health. Sherpa International, British Columbia, Canada.

Rojas, L. X., McDowell, L. R., Cousins, R. J., Martin, F. G., Wilkinson N., Johnson, A. B., and Valesquez, J. B. 1995. Relative bioavailability of two organic and two inorganic zinc sources fed to sheep. J. Anim. Sci. 73:1202-1207.

Rust, S. R. 1985. Effects of zinc methionine and grain processing on performance of growing fattening steers. J. Anim. Sci. 61(Suppl. 1):482(Abstr.).

Shah, B. G. 1981. Chelating agents and bioavailability of minerals. Nutrition Research. 1:617-622.

Smith, M. O., Sherman, I. L., Miller, L. C., and Robbins, K. R. 1995. Relative biological availability of manganese from manganese proteinate, manganese sulfate and manganese monoxide in broilers reared at elevated temperatures. Poultry Sci. 74:702-707.

Spears, J. W. 1988. Evaluation of zinc methionine in ruminant diets. Zinpro Seminar on Zinc methionine in ruminants. Zinpro Corporation, Bloomington, MN.

Spears, J. W. 1989. Zinc methionine for ruminants: Relative bioavailability of zinc in lambs and effects of growth and performance of growing heifers. J. Anim. Sci. 67:835-843.

Spears, J. W., and Samsell, L. J. 1986. Relative availability of zinc in zinc methionine and zinc oxide for ruminants. J. Anim. Sci. 63(Suppl. 1):402(Abstr.).

Suttle, N. F. 1991. The interactions between copper, molybdenum, and sulfur in ruminant nutrition. Annu. Rev. Nutr. 11:121-140.

Suttle, N. F. 1994. Meeting the copper requirements of ruminants. In: Gransworthy, P. C., and Cole, D. J. A. (Ed.) Recent Advances in Animal Nutrition. Nottingham University Press, Loughborough, UK. pp. 173-187.

Suttle, N. F., and Jones, D. G. 1989. Recent developments in trace element metabolism and function: Trace elements, disease resistance and immune responsiveness in ruminants. J. Nutr. 119:1055-1061.

Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition. Academic Press, Inc. New York, New York.

Underwood, E. J. 1981. (Ed.) The Mineral Nutrition of Livestock. Commonwealth Agricultural Bureaux, Farnham Royal Slough SL2 3BN England.

Van Soest, P. 1995. Nutritional Ecology of Ruminants. pp. 122-139. Cornell University Press, Ithaca, New York.

Wakelin, R. L. 1992. Copper supplementation for ruminants. In Trace Elements in Ruminants. Proc. 22nd Seminar. pp. 121-124. Massey University, New Zealand.

Ward, J. D., and Spears, J. W. 1991. Availability of copper in ruminants from copper lysine relative to copper sulfate. J. Anim. Sci. 69(Suppl. 1):554. (Abstr.).

Ward, J. D., Spears, J. W. and Gengelbach, G. P. 1995. Differences in copper status and copper metabolism among Angus, Simmental and Charolais cattle. J. Anim. Sci. 73:571-577.

Wedekind, K. J., Hortin, A. E., and Baker, D. H. 1992. Methodology for assessing zinc bioavailability: Efficacy estimates for zinc-methionine, zinc sulfate and zinc oxide. J. Anim. Sci. 70:178-187.

APPENDIX

Table 1. Supplement composition.

Ingredient	Control	Organic	Inorganic
Cottonseed meal, %	44.52	44.52	44.52
Corn, %	26.52	25.03	26.29
Limestone, %	13.65	13.65	13.65
Potassium chloride, %	5.65	5.65	5.65
Urea, %	5.65	5.65	5.65
Salt, %	2.82	2.82	2.82
Dical, %	.75	0.75	.75
4-Plex, %	0	1.49	0
Rumensin-80, g/ton	1763	1763	1763
Tylan-40, g/ton	961	961	961
Vitamin A-30, g/ton	627	627	627
Vitamin E-50, g/ton	570	570	570
Sodium selenite, g/ton	128	128	128
EDDI, g/ton	5	5	5
Cobalt carbonate, g/ton	0	0	5
Copper sulfate, g/ton	0	0	471
Manganese sulfate, g/ton	0	0	645
Zinc sulfate, g/ton	0	0	952

Table 2. Feedlot performance of steers supplemented with inorganic, organic (Zinpro 4-plex®) or no trace minerals.

Item	Control (1)	Inorganic (2)	4-Plex (3)	SEM	1 vs 2&3 P=	2 vs 3 P=
Live weight, lb.						
Start	501	501	502	3.25	.91	.97
Day 218	1157	1193	1180	18.61	.21	.60
ADG, lb.						
Day 0 to 104	2.96	3.05	2.83	.12	.90	.19
Day 104 to 218	3.15	3.40	3.46	.10	.03	.70
Day 0 to 218	3.10	3.24	3.13	.09	.40	.36
Intake, lb.						
Day 0 to 104	14.2	14.5	13.8	.27	.99	.12
Day 104 to 218	19.4	20.2	19.1	.37	.57	.09
Day 0 to 218	16.8	17.2	16.5	.23	.91	.08
Feed: Gain						
Day 0 to 104	4.24	4.22	4.34	.07	.67	.28
Day 104 to 218	5.48	5.27	4.90	.18	.13	.21
Day 0 to 218	4.83	4.71	4.68	.10	.29	.82

Table 3. Carcass characteristics of steers supplemented with inorganic, organic Zinpro 4-plex®) or no trace minerals.

Item	Control	Inorganic	4-Plex	SEM	2&3 vs 1	2 vs 3
	(1)	(2)	(3)		P=	P=
Hot weight, lb.	735	758	748	12.15	.22	.56
Dress, %	62.5	62.9	62.7	.36	.52	.63
Marbling Score	290	297	276	13.5	.83	.27
Choice, %	33.3	39.2	30.8	9.8	.93	.56
Select, %	54.2	60.8	60.0	9.9	.56	.93
Standard, %	12.5	0.0	9.2	5.2	.21	.21
Backfat, in	.39	.46	.40	.03	.37	.14
KPH, %	2.0	2.2	2.2	.10	.06	.96
Yield grade	2.5	2.7	2.4	.12	.66	.13
REA, in^2	13.0	13.4	13.6	13.4	.20	.62
Liver condemned, %	16.7	21.7	18.3	7.9	.74	.78

Table 4. Blood concentrations of minerals (ppm) at the start of the experiment and at the end of the experiment 204 days later for steers fed no supplemental Zn, Mn, Co, and Cu or fed these minerals from inorganic or organic (Four-Plex) sources based on pen means.

MINERAL	Ca	Cu	Fe	Mg	P	Zn	Na	K
INITIAL MEANS	96.43	1.12	1.09	20.68	73.96	0.81	3,151	188
CONTROL	95.48	***.70***^{x}	2.07^{xy}	22.35	76.86	1.01	3,133	332^{x}
INORGANIC	94.65	***.75***	2.47	21.78	72.96^{b}	1.08	3,090	367
FOUR-PLEX	96.22	***.73***	2.75	21.65	76.68^{a}	1.14	3,115	372
SUPPLEMENT (P <)	.96	.04	.01	.27	.12	.08	.16	.05
SOURCE (P<)	.17	.53	.16	.85	.03	.33	.29	.76

^{x} Differs (P<.05) from mean of cattle fed supplemental minerals

^{y} Change from initial value was greater (P<.05) when added minerals were fed.

^{a,b} Means with different superscripts differ (P<.05).

Values in italics fall below minimums suggested by Puls (1988) and Michigan State Diagnostic Laboratory.

Table 5. Liver concentrations of minerals (ppm) at the start of the experiment and 204 days later for steers fed no supplemental Zn, Mn, Co, and Cu or fed these minerals from inorganic or organic (Four-Plex) sources based on pen means.

MINERAL	Ca	Cu	Fe	Mg	Mn	P	Zn	Co	Na	S	K
INITIAL MEANS	735	135.4	324	664	***6.79***	10,845	208	1.176	4,225	7164	11,326
CONTROL	115	111	***125***	607	***7.94***	11,788	106.1	.54	***1,690***	7719	9,898
INORGANIC	115	162	***124***	622[a]	***7.88***	11,725	104.4	.45[b]	***1,712***	7551	9,964[a]
FOUR-PLEX	111	151	***107***	599[b]	***8.12***	11,365	101.1	.83[a]	***1,718***	7350	9,486[b]
SUPPLEMENT (P <)	.49	.22	.28	.51	.85	.44	.41	.18	.58	.17	.29
SOURCE (P<)	.21	.78	.10	.01	.54	.32	.47	.01	.91	.35	.03

[x] Differs (P<.05) from mean of cattle fed supplemental minerals

[a,b] Means with different superscripts differ (P<.05).

Values in italics fall below minimums suggested by Puls (1988) and Michigan State Diagnostic Laboratory.

TABLE 6. Blood concentrations of minerals (ppm) at the start of the experiment and at the end of the experiment 204 days later for cattle with various sire breeds.

MINERAL	Ca	Cu	Fe	Mg	P	Zn	Na	K
ANGUS	98.97^{a}	.75^{ab}	2.46^{ab}	22.11	72.81^{b}	1.10^{ab}	3,144^{ab}	331
GELBVIEH	93.50^{b}	.82^{a}	2.52^{ab}	21.96	78.20^{ab}	1.09^{ab}	3,159^{ab}	333
LIMOUSIN	95.62^{b}	.74^{ab}	2.69^{a}	21.76	78.49^{a}	1.14^{a}	3,146^{a}	373
HEREFORD	94.97^{ab}	.73^{ab}	2.18^{b}	21.38	72.65^{ab}	1.10^{ab}	3,081^{ab}	367
CROSSBRED	94.67^{b}	.70^{b}	2.32^{b}	21.98	74.95^{ab}	1.04^{b}	3,089^{b}	359
BREED (P<)	.06	.04	.09	.97	.14	.38	.10	.55

^{a,b} Means with different superscripts differ (P < .05).

TABLE 7. Liver concentrations of minerals (ppm) at the start of the experiment and at the end of the experiment 204 days later for steers with different sire breeds.

MINERAL	Ca	Cu	Fe	Mg	Mn	P	Zn	Co	Na	S	K
ANGUS	118^{ab}	142^{ab}	120	600	7.38^{c}	11534	104	.49	$1,778^{a}$	7,463	9,585
GELBVIEH	114^{ab}	191^{ab}	109	622	9.59^{a}	11,845	99	.86	$1,734^{ab}$	7,812	9,666
LIMOUSIN	118^{a}	148^{ab}	119	619	8.09^{bc}	11,523	102	.74	$1,641^{b}$	7,503	9,905
HEREFORD	116^{ab}	226^{a}	134	625	9.22^{ab}	12,066	116	.30	$1,690^{ab}$	8,006	10,362
CROSSBRED	110^{b}	124^{b}	117	604	7.80^{c}	11,609	104	.58	$1,710^{ab}$	7,496	9,732
BREED (P<)	.18	.10	.67	.53	.02	.86	.38	.22	.39	.50	.40

^{a,b} Means with different superscripts differ ($P < .05$).

VITA

Mehmet Basalan

Candidate for the Degree of

Master of Science

Thesis: TRACE MINERAL SUPPLEMENTATION OF STEERS: EFFECTS OF ORGANIC AND INORGANIC SOURCES ON PERFORMANCE AND CARCASS CHARACTERISTICS

Major Field: Animal Science

Biographical:

Personal Data: Born in Kalecik, Ankara, Turkey, on November 1, 1970, the son of Osman and Sakize Basalan.

Education: Graduated from Bahcelievler Teknik ve Endustri Meslek Lisesi, high school, Ankara, Turkey in June 1987; received Bachelor of Science degree in Veterinary Medicine from Ankara University, Ankara, Turkey in September 1992. Completed the requirements for the Master of Science degree with a major in Animal Science at Oklahoma State University in July 1996.

Experience: Raised and worked in a farm near Ankara, Turkey. Employed by Kirikkale University, Department of Veterinary Medicine in Turkey, 1993 to present.